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THE INFLUENCE OF METEOROLOGICAL CONDITIONS ON THE POWER OUTPUT OF TRACTORS

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Agricultural Memorandum 948

1. Introduction

This study was commissioned following a three year survey by the Mechanisation Department of Wales on the power output and fuel usage by tractors on the farm. It is hoped that the work presented here will be included in future Mechanisation reports on tractor performance.

The performance of an engine is affected by the temperature and pressure of the atmosphere. High pressures and low temperatures cause the air to become more dense which improves the combustion efficiency of the engine (Hull, 1983). Turbocharged engines have been found to maintain performance better than naturally aspirated engines under conditions of decreasing barometric pressure (Sims et al, 1979) but this study has been confined to the naturally aspirated diesel engined tractor which remains the most popular in this country.

New models of tractors are usually submitted by a manufacturer to an OECD(Organisation for Economic Co-operation and Development) test at the NIAE, Silsoe. The test will examine many aspects of tractor performance and the report produced will frequently form the basis of the manufacturers sales literature for his product.

Atmospheric conditions (pressure, temperature and humidity) are recorded while the engine performance is monitored on a dynamometer and are stated in the test report. Several factors have been devised (see Appendix 1) to standardise the maximum power of the OECD test by removing the influence of atmospheric conditions. This enables maximum power outputs to be compared on an equivalent basis.

One such factor frequently used in this country is the din correction factor or DCF which originated in Germany and is based upon 'standard' values for pressure and temperature of 1013 mb and 20°C respectively. The formula used is:

$$DCF = \frac{1013}{P}\sqrt{\frac{273 + T}{293}}$$

where P and T are the pressure and air temperature recorded during the OECD test.

As an illustration consider that two tractors are to be tested on separate days.

Tractor 1, day 1

Pressure 1013 mb. Air temperature 20°C DIN CF = $\frac{1013}{1013}\sqrt{\frac{273 + 20}{293}} = 1.0$

Tractor 2, day 2

Pressure 988 mb Air temperature 18°C DIN CF = $\frac{1013}{988}\sqrt{\frac{273 + 18}{293}} = 1.02$

Tractor 1 gave 63.4 KW maximum power and no correction is applied (DCF = 1.0). Tractor 2 gave 63.0 KW in the test giving a corrected power of 63.0 x 1.02 = 64.3 KW. Under identicle conditions of pressure and temperature tractor 2 would develop more power than tractor 1. If tractor 1 were tested on both of these days the maximum

power recorded on days 1 and 2 would have been 63.4kw and 62.2kw respectively ie 2% less on the second day due to atmospheric conditions. A further illustration is given in Fig. 1.

2. Objectives

The primary aim of this study is to determine whether the prevailing weather conditions in this country can produce a significant change in the power output of a tractor engine, and if so when this was most likely to occur. It should then be possible to establish the relevance of these figures with regards to tractor performance in the field.

3. Data analysis

Five meteorological stations with 3-hourly reports of pressure and dry bulb temperature over a twenty year period 1961-80 were chosen to illustrate the power output variation over the country. Details of the stations are shown in Table 1.

TABLE 1

Stations used in the analysis

	N.G.R.		County	Height a.s.l.
Aberporth	2239	2520	Dyfed	144
Eskdalemuir	3235	6026	Dumfries and Galloway	242
Manston	6335	1666	Kent	44
Plymouth	2492	0529	Devon	27
Waddington	4988	3653	Lincolnshire	68

A frequency analysis was performed (using a standard meteorological program) for each station taking each month separately for the whole period. The layout was as follows.

1961-80

MONTH:	HOUR (GMT)				
	00	06	12	18	
DIN CORRECTION FACTOR	03	09	15	21	TOTAL
≤ 0.870					
0.871 TO 0.879					
0.880 TO 0.889					
. . . . .					
1.110 TO 1.119					
≥ 1.120					

The 8 synoptic hours were split into 4 groups of 2 so that day (observations at 06, 09, 12 and 15 GMT) and night (00,03, 18 and 21) time periods could be looked at separately.

A second frequency analysis was performed for Aberporth of dry bulb temperature against pressure, subdivided into increments of 10 between - 30 and 40°C for temperature and 950 and 1050 mb for pressure.

4. Results

The size of the power change is shown by the difference in DCF: values greater than unity indicate that the engine is working below 'standard' efficiency due to low pressures and high temperatures at the time of the OECD test and vice-versa for DCF less than one. See Fig 1.

The mean seal leavel pressure ranges between 1007 to 1016 mb in January and 1012 to 1018 mb in July (Lamb, 1964). The 1941-70 mean daily average temperature ranges between 2.5 to 7.5°C and 12.5 to 17.5°C in January and July respectively (Climate memo. no. 73). These give an average DCF in the range 0.97 to 0.98 in January and 0.98 to 1.0 in July.

4.1 Annual variation

A cumulative frequency curve of DCF for all months was plotted for every station (Fig. 2) The most striking point to emerge is that almost 100% of days have a din factor less than one and the curves for each site follow one another very closely indicating that the weather exerts similarly influences across the whole country. The median and inter-quartile range (iqr) are shown on the graph; 5 days in 10 a din correction of 0.975 must be applied to the OECD figure.

4.2 Month by month variation

This study was confined to Aberporth. Fig 3 shows a plot of median and iqr for each month. The median DCF gradually increases while the iqr gradually decreases during the progression from winter to Summer months giving a maximum change of 1% between February and August. This suggests that the tractors will perform slightly better in winter when high pressures and low temperatures are more frequent.

This analysis was extended to consider day and night separately but virtually no difference was found between the two sets of figures (Fig. 4).

4.3 Maximum power change

The maximum power change during the 20 year period is found by comparing the two extreme values of DCF. This was done for Aberporth and the results are given in Fig.5, the number of occasions with each pressure/temperature combination being superimposed on the grid. The pressure and temperature varied between 960 to 1050 mb and - 10 to 30°C respectively giving a DCF in the range 0.91 to 1.06 ie a 15% difference. Clearly this is exceptional but changes of the order of 6 to 7% could occur on a day to day basis.

4.4 Relating the power change to engine performance

The performance characteristics of an engine are most often expressed in terms of a power take off (PTO) curve and a corresponding equivalent crankshaft torque curve. The PTO curve represents the power available to drive ancilliary equipment and will be less than the maximum power developed at the flywheel due to power loss through the transmission. The available torque is also very important in determining the suitability of a tractor for particular field operations (Hull, 1983).

The PTO and torque curves for a popular 56 KW (75 HP) tractor are shown in solid lines in Fig 6. These curves were taken from an actual OECD test report dated 23 March 1979, when the pressure = 1014 mb, air temperature = 18°C and RH = 48% giving a DCF = 0.996.

Meterological records at Waddington in Lincolnshire, comparable to those at Silsoe, indicate that a DCF in the range 0.99 to 0.999 will occur on average for about 1/6 th of the time ($\frac{3}{4}$ of occasions the DCF will be < 0.990). A more appropriate PTO curve can be drawn by taking the median value of 0.975 from Fig 2; this in fact means that in 5 OECD tests out of 10, the maximum power measured would have been $2\frac{1}{2}$% more than was actually measured on 23 March 1979. The dashed line in Fig 6 shows the PTO curve for median conditions.

It is not clear whether the din correction factor is also applicable to engine torque (which is dependent upon power x speed) and so this curve has been left unchanged.

5. Discussion

The total power requirement for forage harvesting in Wales has been steadily rising and higher powered tractors are being purchased to cope with the larger tonnages of silage being made (Hull, 1983). Therefore there is a need for power outputs to be accurately measured by the OECD test so that the farmer is in a position to choose a tractor with adequate power to suit his needs.

The din correction factor provides a useful means of comparting tractor power by eliminating the meteorological effects. However it takes no account of the fuel/air ratio in determining the correction which is known to affect engine performance - only the British Standard procedure does this (Mathews 1970). Furthermore, the din factor originated in Germany where a continental climate prodominates: this is reflected in DCFs below one on most occasions. Despite these problems, din is widely used in this country and as such is worthy of study.

The analysis for Aberporth* revealed that engine power may change by as much as 15% during extreme weather conditions. A figure of 3% is more likely, however, on a day-to-day basis which for a 70hp tractor represents a 2hp difference. It is possible that this could be significant when working in mountainous terrain or on poor ground conditions.

The validity of the OECD test must be assessed in terms of these figures. The test requirement is for the ambient air temperatures** to be between 15 and 27°C and the pressure to be not less than 970 mb (OECD, 1980). In the case of Aberporth these limits would allow a DCF in the range 0.96 to 1.05 ie a 10% difference.

The International Standards Organisation (ISO) is currently working on a standard correction factor but as yet the exact relationship has not been agreed. Once finalised, it would seem reasonable to include this correction factor in the official testing of tractors.

* Aberporth has a maritime climate and one will experience greater fluctuations in temperature and pressure regimes, and hence in engine performance, further inland.

**The air temperature is measured at two points - one 2m in front of the tractor 1.5m above ground and the other at the engine air intake.

6. Conclusion

The weather in the British Isles can produce a significant change in the performance of an engine, particularly during adverse conditions. There is a case for modifying the OECD testing procedure to incorporate corrected power output figures using the din, or some other, correction factor to eliminate the weather effects.

7. Acknowledgements

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Hull, P J (1983). Power output and fuel usage by tractors on the farm.

Lamb, H H (1964). The English Climate (2nd Edition) London: English Universities Press.

Meteorological Office (1975). Maps of mean and extreme temperature over the United Kingdom 1941-70. Climatological Memorandum 73.

Mathews, J (1970) Notes on the proposal for inclusion of exhaust smoke measurements and Power corrections in tractor tests. NIAE Departmental Note DN/TE/30/70

OECD (1980) Amending the decision of the Council establishing the OECD standard codes for the official testing of agricultural tractors. Paris, 24 July. C(80)60 (Final).

APPENDIX 1

Engine Power Correction factors

At the present time there are at least four standardised procedures for correcting engine power measurements for departures from standard ambient temperature and pressure values (Matthews, 1970). These are:

a. Draft ISO (ISOTC/22). Draft ISO recommendation No 1585)

Standard conditions are 20°C and 760 mm pressure. The correction, Kd by which the measured power must be multiplied, takes no account of the fuel to air ratio (except that the ratio must be stated if outside the range 50-100 mm^3/litre) and is given by the equations

$$Kd = 1 + \frac{A}{100} \text{ where } A = 0.085\ (760 - p) + 0.17\ (T - 293)$$

and T is the test temperature and p the ambient pressure.

b. Germany, DIN 70020

This is discussed in the text.

c. SAE Recommendation J.816

Standard conditions take into account the generally higher temperatures and altitude throughout the US continent and are 85°F (29.5°C) and 29.38 in pressure (745 mm).

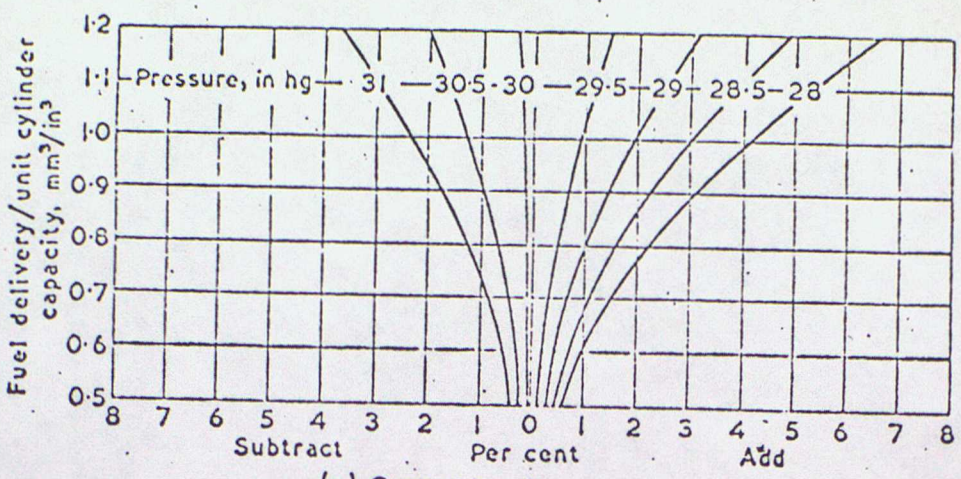
The correction factor, C_D, by which the measured power value is multiplied to obtain power at standard conditions is given by

$$C_D = \frac{29.00}{B_t} \times \left(\frac{t_t + 460}{85 + 460}\right)$$

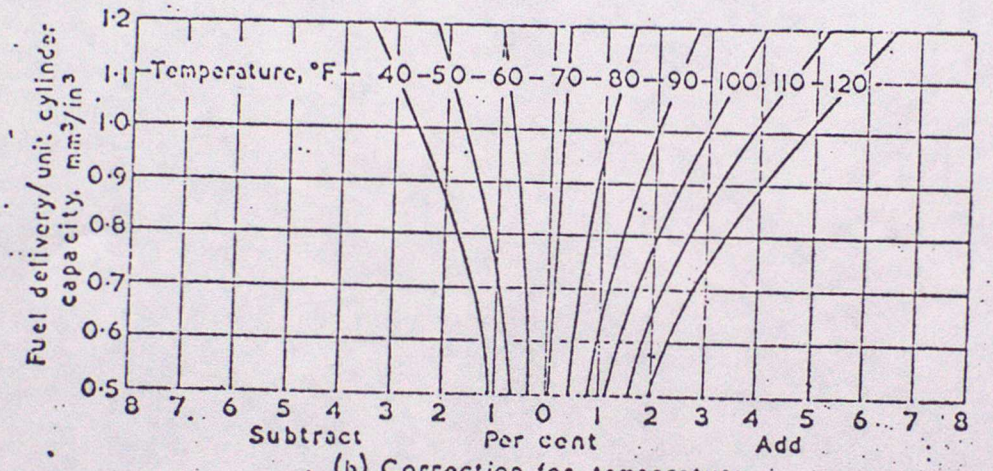
where B_t is the ambient pressure during the test (in inches) and t is the temperature (in °F). If outside the ranges 28-31 ins pressure or 40-120°F temperature, the ambient conditions during the test must be stated alongside the corrected results.

d. United Kingdom BS AU141

This correction takes into account the fuel to air ratio with corrections given in both graphical and algebraic form. Standard conditions are 20°C and 760 mm and the correction is graphical (see figure).

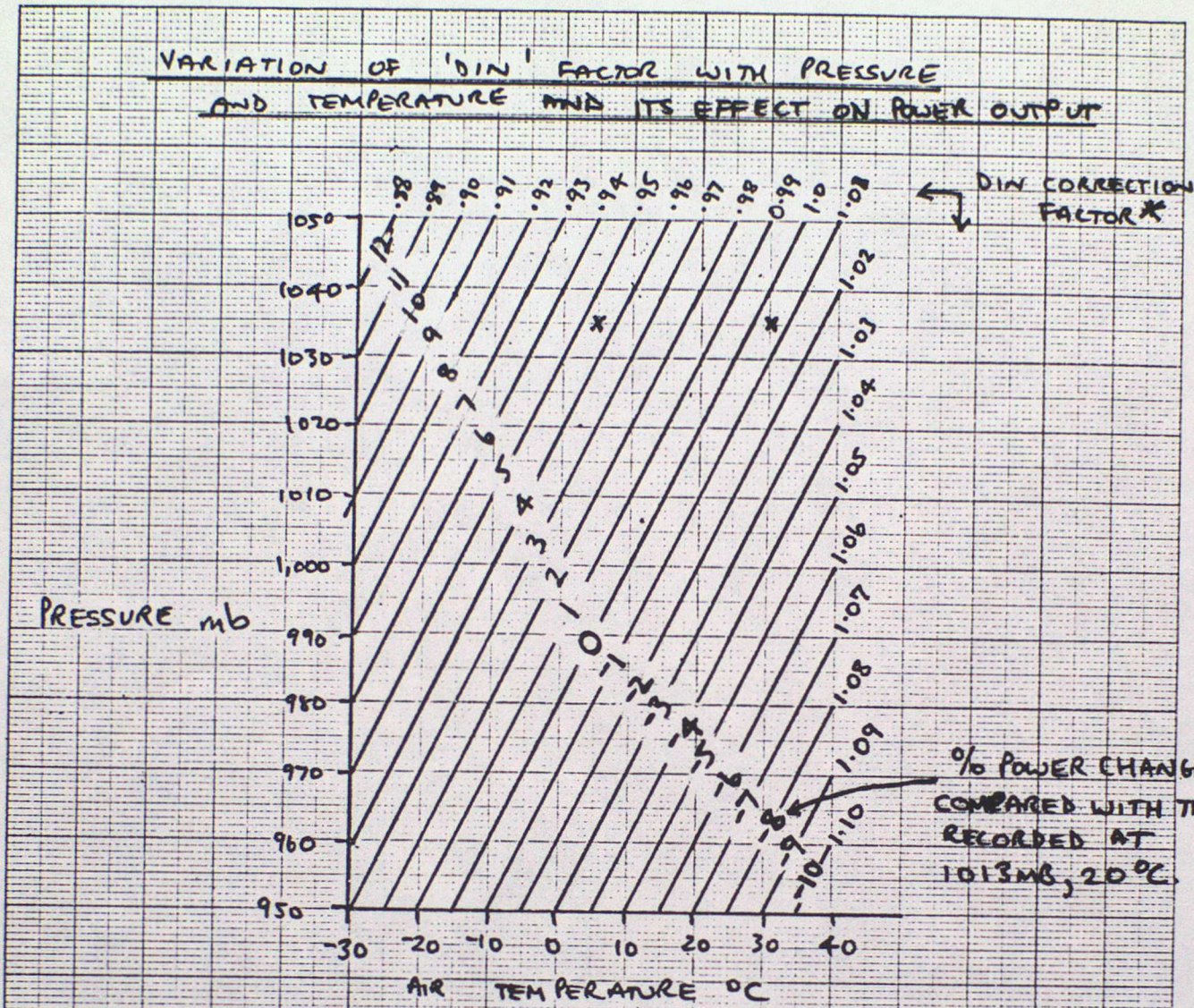


(a) Correction for pressure



(b) Correction for temperature

FIGURE 1


VARIATION OF 'DIN' FACTOR WITH PRESSURE AND TEMPERATURE AND ITS EFFECT ON POWER OUTPUT
DIN CORRECTION FACTOR*
.88 .89 .90 .91 .92 .93 .94 .95 .96 .97 .98 0.99 1.0 1.01 1.02 1.03 1.04 1.05 1.06 1.07 1.08 1.09 1.10
12 11 10 9 8 7 6 5 4 3 2 1 0 -1 -2 -3 -4 -5 -6 -7 -8 -9 -10
% POWER CHANGE COMPARED WITH THAT RECORDED AT 1013MB, 20°C.
PRESSURE mb
1050 1040 1030 1020 1010 1,000 990 980 970 960 950
-30 -20 -10 0 10 20 30 40
AIR TEMPERATURE °C

EXAMPLE

A tractor is being used on two days, marked by a x on the above graph. The difference in developed maximum power by the engine is $4\frac{1}{2} - -\frac{1}{2} = 5\%$

* THESE FIGURES ARE NOT EXACT DUE TO ROUNDING ERRORS AND THE LINEAR REPRESENTATION OF THE NON-LINEAR REPRESENTATION FOR DCF.

FIGURE 1

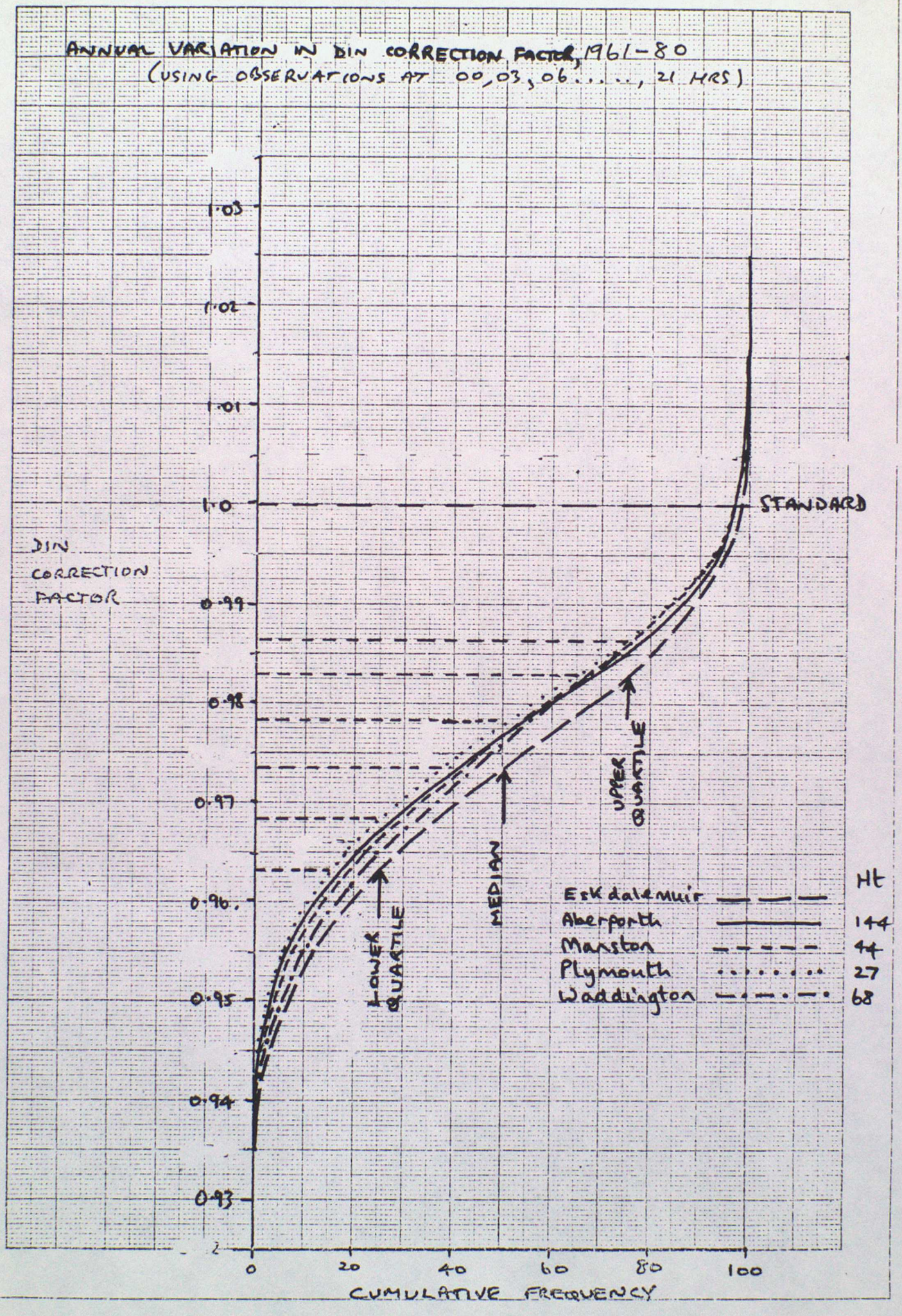

ANNUAL VARIATION IN DIN CORRECTION FACTOR, 1961-80
(USING OBSERVATIONS AT 00, 03, 06 ..... , 21 HRS)
DIN CORRECTION FACTOR
1·03
1·02
1·01
1·0
0·99
0·98
0·97
0·96
0·95
0·94
0·93
STANDARD
LOWER QUARTILE
MEDIAN
UPPER QUARTILE
Ht
Eskdalemuir
Aberporth 144
Marston 44
Plymouth 27
Waddington 68
0
20
40
60
80
100
CUMULATIVE FREQUENCY

FIGURE 3

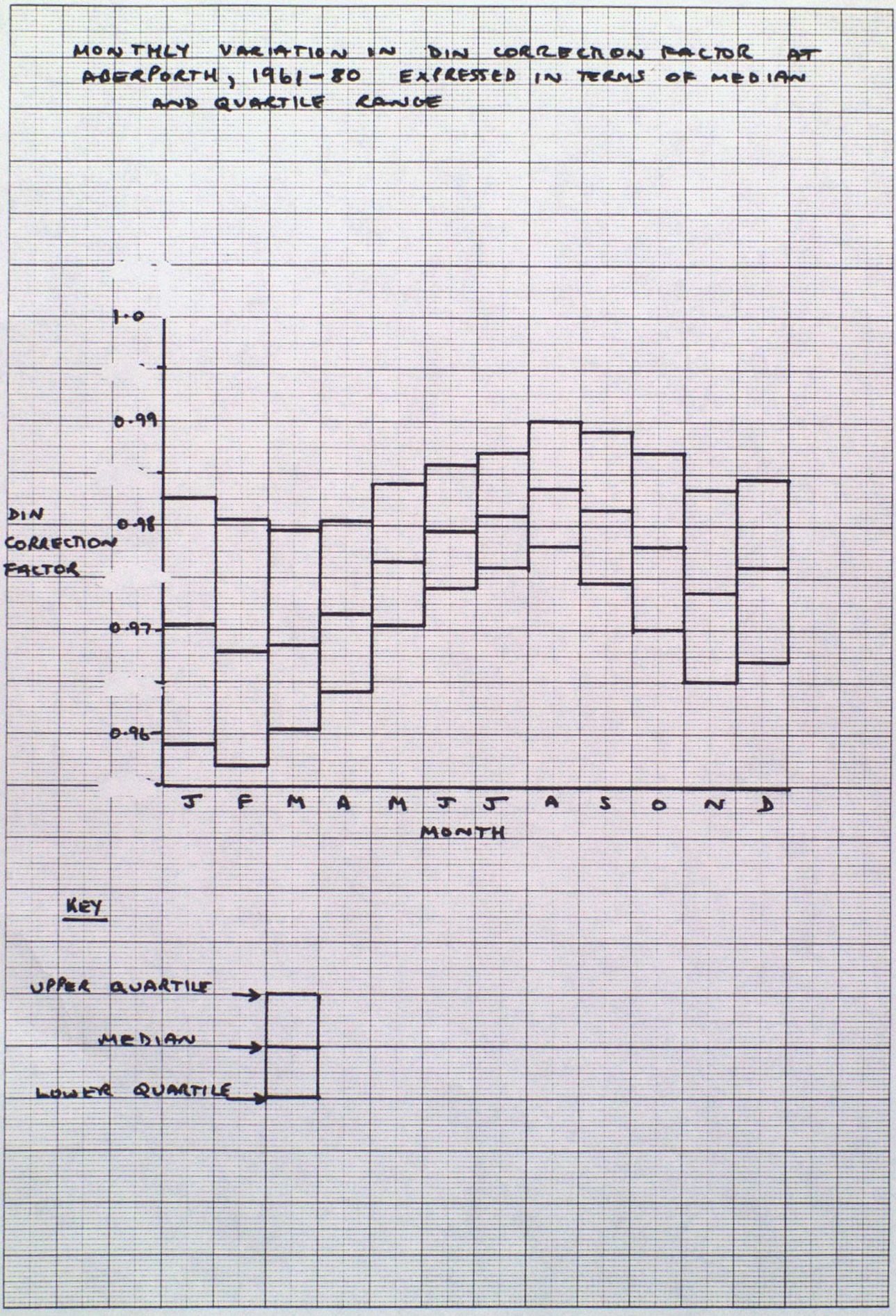

MONTHLY VARIATION IN DIN CORRECTION FACTOR AT ABERPORTH, 1961-80 EXPRESSED IN TERMS OF MEDIAN AND QUARTILE RANGE
1·0
0·99
0·98
0·97
0·96
DIN CORRECTION FACTOR
J F M A M J J A S O N D
MONTH
KEY
UPPER QUARTILE
MEDIAN
LOWER QUARTILE

FIGURE 4

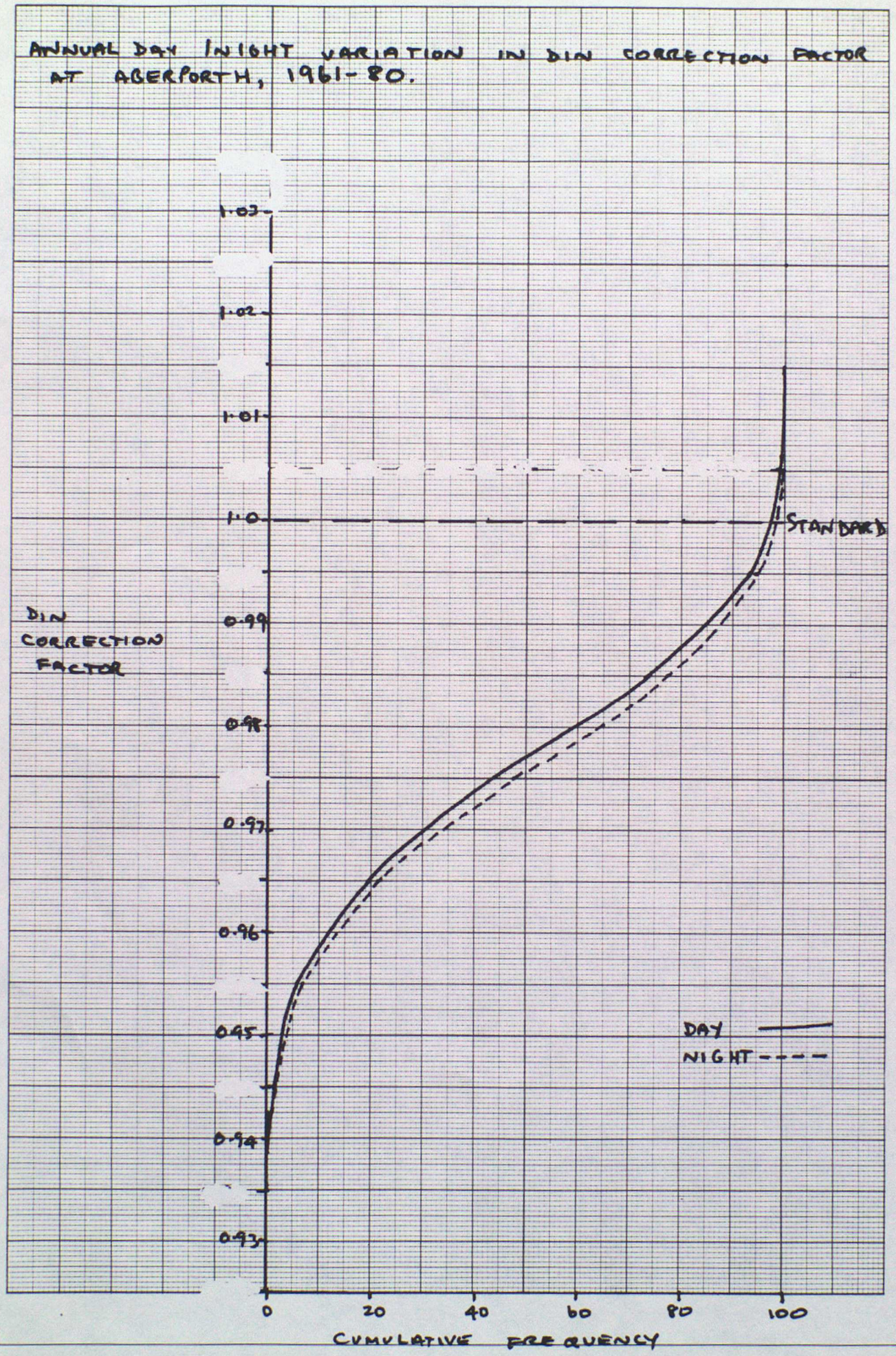

ANNUAL DAY/NIGHT VARIATION IN DIN CORRECTION FACTOR AT ABERPORTH, 1961-80.
1·03
1·02
1·01
1·0
0·99
0·98
0·97
0·96
0·95
0·94
0·93
STANDARD
DIN CORRECTION FACTOR
DAY
NIGHT
0
20
40
60
80
100
CUMULATIVE FREQUENCY

FIGURE 5

VARIATION + FREQUENCY OF OCCURRENCE OF DIN CORRECTION FACTOR WITH PRESSURE AND TEMPERATURE AT ABERPORTH, 1961-80

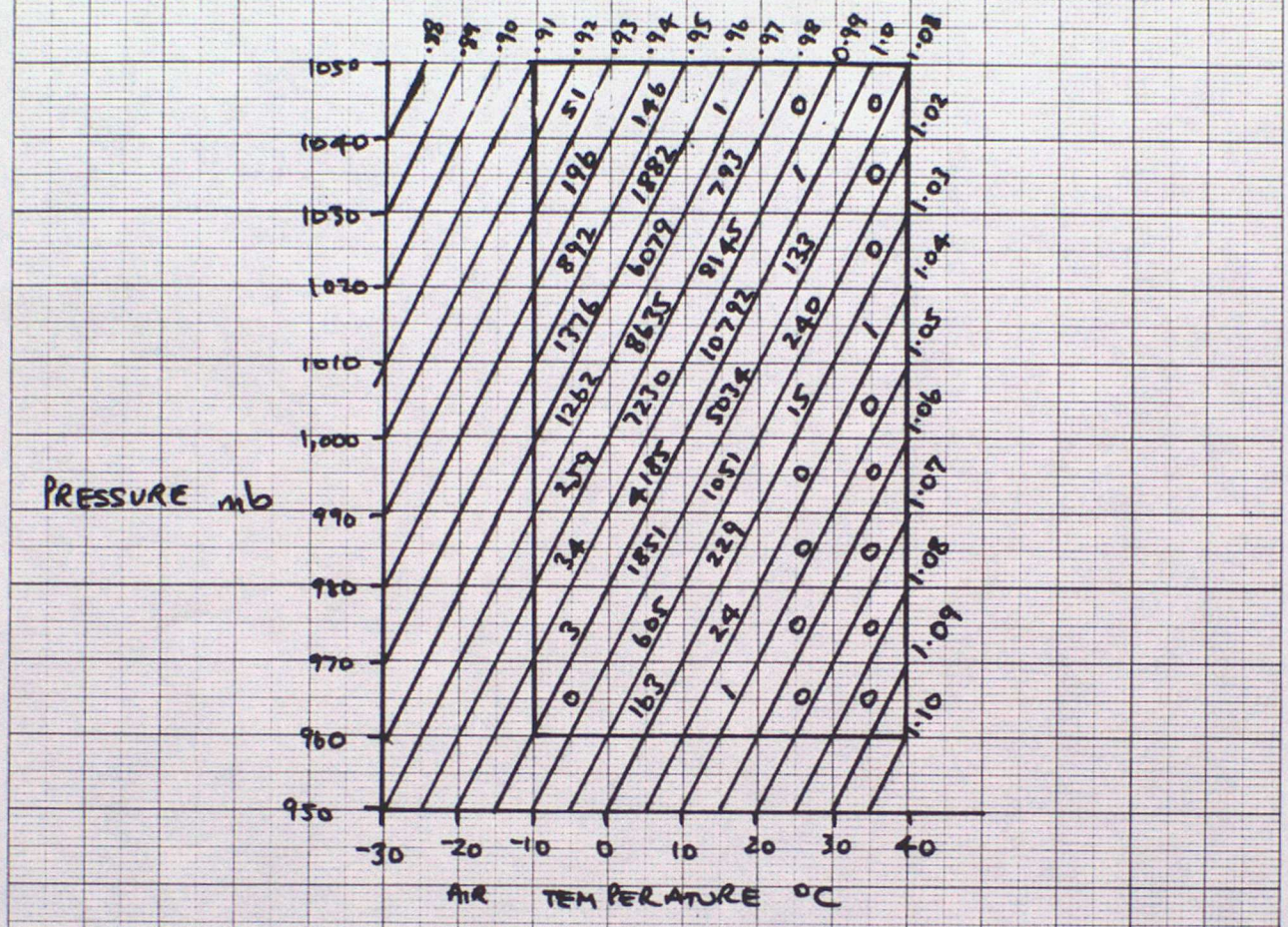
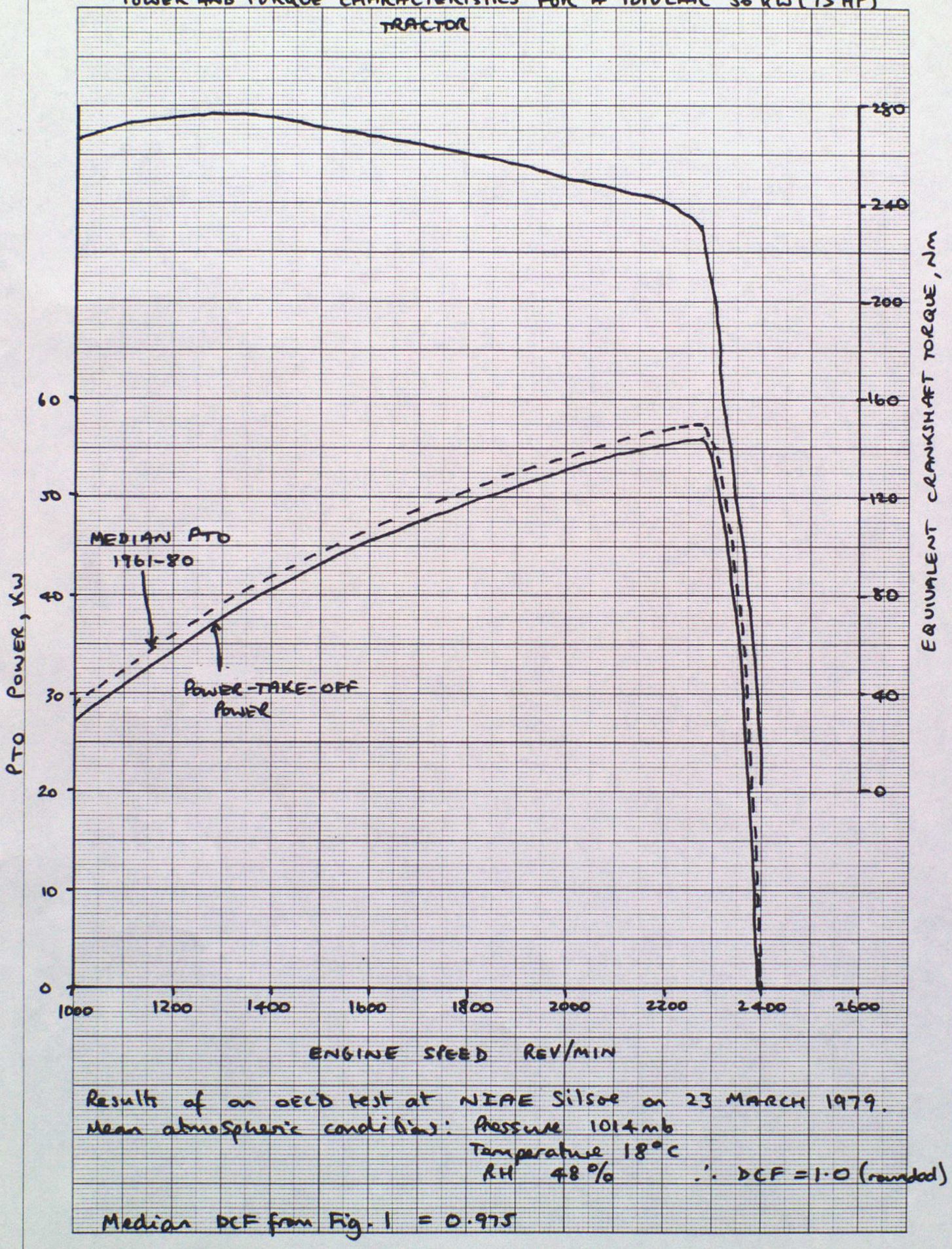


FIGURE 6

POWER AND TORQUE CHARACTERISTICS FOR A POPULAR 56 KW (75 HP) TRACTOR



Results of an OECD test at NIAE Silsoe on 23 MARCH 1979.
Mean atmospheric conditions: Pressure 1014 mb
Temperature 18°C
RH 48%
∴ DCF = 1·0 (rounded)

Median DCF from Fig. 1 = 0·975